Can El Niño amplify the solar forcing of climate?

A. Ruzmaikin

Abstract. ENSO (El Niño and the Southern Oscillation) is considered as a stochastic driver that excites the atmospheric anomaly states, such as Pacific North American pattern. This can make the 11-year solar activity forcing feasible to climate through stochastic resonance -- a phenomenon that amplifies a weak input to a nonlinear bistable system by the assistance of noise.

In contrast to the clearly identified anthropogenic forcing, such as the rising carbon dioxide input into the atmosphere, effects of solar activity on climate are believed to be currently weaker and more subtle. Particularly controversial is a role of the 11-year solar activity forcing in climate change. On one hand, there is an 11-year signal in the Earth's global temperature spectrum (1). On the other hand, this signal is noisy and transient (2), and could be easily damped on the decadal scale by the inertia of oceans.

At present, there are two schools of thought in regards to a possible way by which variations of solar activity can influence the weather-climate parameters of the Earth. According to one school (3,4), the variations of the solar irradiance affect the atmosphere. This could be either the total irradiance which penetrates down to the Earth's surface or the UV part of the irradiance which affects the stratospheric parameters. Variations of irradiance, however, are small, only 0.1% per solar cycle as measured from space (3). According to another school (5-7), the variations of the flux of galactic cosmic rays (energetic particles), modulated by the solar activity, influence the cloud cover and hence the climate. The variations of cloudiness due to the cosmic rays are large, about 3% to 4% per cycle, as evaluated from cloud data during a recent solar cycle (7). The cloud optical thickness, however, varies in antiphase with the cloudiness (8) weakening the resulting weather-climate effect of cosmic rays.

Alexander Ruzmaikin, Jet Propulsion Laboratory, m/s 169-506, Pasadena CA 91109

The atmospheric response to a weak solar forcing may be amplified through an assitance of noise inherent to the atmosphere. In contrast to the old common belief of minimizing noise effects in communications, recent research has demonstrated that noise can play a constructive role in detection of weak signals through the phenomenon called "stochastic resonance", for a review see (9). The phenomenon is simply demonstrated by considering a system with two states separated with a threshold. An input low frequency signal with an amplitude lower than the threshold can not excite the higher-energy state. When however in addition to the signal this state is excited by random kicks, the signal can become feasible through the modulation of the noise (grouping of kicks). The modulation at a given frequency of the signal is optimal at some level of noise -- this justifies the term "stochastic resonance", not be confused with the standard concept of resonance. The stochastic resonance has been observed in many physical systems (ring lasers, semiconducters, chemical reactions) and it is a good clue to understanding some natural phenomena. Originally, the stochastic resonance was introduced to explain switchings of climate between ice ages and warm periods as caused by weak periodical variations of the Earth's orbital parmeters assisted with noise (10). Recently this mechanism has been proposed to explain the origin of the intermittent 11-year global Earth's temperature variations (11). However the nature of the noise has not been identified. Here it is suggested that the noise capable of amplifying the solar activity forcing is generated by series of El Niño events.

The anomalous warming of the eastern equatorial part of the Pacific Ocean (El Niño) and the coupled Southern Oscillation in the atmosphere are known to combine regular features at some characteristic frequencies with the irregular, chaotic behavior (12). The broadband spectrum of the Southern Oscillation Index has a hat-type distribution over 2-7 years. Thus the maximum of its power is located at scales close to half the period of the 11-year solar activity signal. From the theory of stochastic resonance, it is known that a weak periodic signal can most effectively be amplified when its period is close to twice the characteristic time of the noise (9). Some observational support for a possible relationship between the ENSO and solar activity forcing comes from the fact that global cloud thickness variations are correlated with both the solar cycle and ENSO (8).

It is now well established that the effects of ENSO are global, i.e. there are largescale atmospheric responses to the El Niño anomalous heating of the ocean (13). One major global response has been identified with the excitation of a normal-mode observed in the form of atmospheric pressure structures at 200 Mb geopotential height and called ``Pacific North American" (PNA) and ``East Atlantic" patterns (14, 15). It is not clear at present if these patterns are excited linearly or nonlinearly (through a threshold). The nonlinear type of excitation is assumed here. The existence of a threshold is supported by numerical GCM experiments (16), in which it was shown that the amplitude of the atmospheric response becomes insensitive to an increase of forcing beyond some value of the forcing. To simplify the situation it is assumed here that the atmosphere has two states: a normal, stable atmospheric state separated by a threshold from an anomalous, unstable state. The basic idea of this paper is that weak (sub-threshold) solar activity forcing becomes effective when the anomalous state is excited by El Niño events.

In the model below no physical process by which the solar activity can affect the anomalous state is specified. Solar forcing is simply introduced as proportional to the observed variations of solar activity. This approach, at least at the present level of knowledge, is justified by observational evidence indicating high correlations between the locations of atmospheric semi-permanent pressure systems (the centers of actions, such as the Aleutian Low and Hawaiian High) and the phase of the solar cycle (17). It has also been pointed out that storms tracks in the Northern Atlantic are displaced equatorward at solar maximum relative to solar minimum (18).

As a mathematical presentation of the suggested idea a simple model of a stochastic resonance in a circular phase space (19) can be used:

$$d\varphi/dt + \sin\varphi = p + e(t) + \varepsilon \cdot s(t), \tag{1}$$

where $p < 1$ is a parameter, $e(t)$ is a sequence of events generated by ENSO, and ε is a small amplitude of the solar activity signal $s(t)$. The basic variable φ, some climate index, characterizes the state of the atmosphere. In the absence of noise and solar signal this system has two equilibrium states which are identified here with the normal state of the atmosphere and with the anomalous state (PNA type structure). These states are defined by the condition $\sin\varphi = p$: a stable $\varphi_s = \arcsin(p)$ state, and an unstable $\varphi_u = \pi - \arcsin(p)$ state. The stability of these states can easily be checked by a perturbation of the equilibrium, or by representing the terms $- \sin\varphi + p$ in Eq. (1) through a potential $-\partial U/\partial\varphi$, with $U = -\cos\varphi + px$ (Fig. 1) having a generic form.

The value of ε is chosen such that the solar signal is less than threshold (the distance $\varphi - 2\arcsin(p)$ between the two states) and thus alone can not move the system from the normal to the anomalous state. Driven only by the irregular events $e(t)$, the state point φ jiggles around the stable state and, from time to time when the amplitude of an event is large enough, goes over the threshold and moves into the unstable state. After the time $\sec\varphi_u$, a mean residence time in the unstable state, the point returns back to the stable state. Thus the ENSO forcing alone produces a random sequence of events. Acting together, however, the two forcings produce different output. The solar forcing modulates (groups) the ENSO events so that an 11-year signal becomes feasibile.

As a specific example, the time series of ENSO for the period 1950-1996 and the solar activity forcing for the same period (Figure 2 upper panel) are taken as inputs to right side of Eq. (1) with $p = 0.5$ and $\varepsilon = 0.005$. Here we use the sunspot number time series as a proxy for the solar activity. If the solar forcing were specified (irradiance or cosmic ray particles), one could use the irradiance proxy or cosmic ray flux proxy instead. A solid horizontal line in this Figure marks the threshold between the normal and anomalous states. Eq. (1) then has been integrated numerically. The function describing the events corresponding to the situation when the solution is above the threshold, i.e. the system is in the anomalous state, is shown in the middle panel of this figure. The events are normalized to a unit amplitude. The duration of an event (a rectangular impulse) is the residence time the system spends in the anomalous (PNA type) state.

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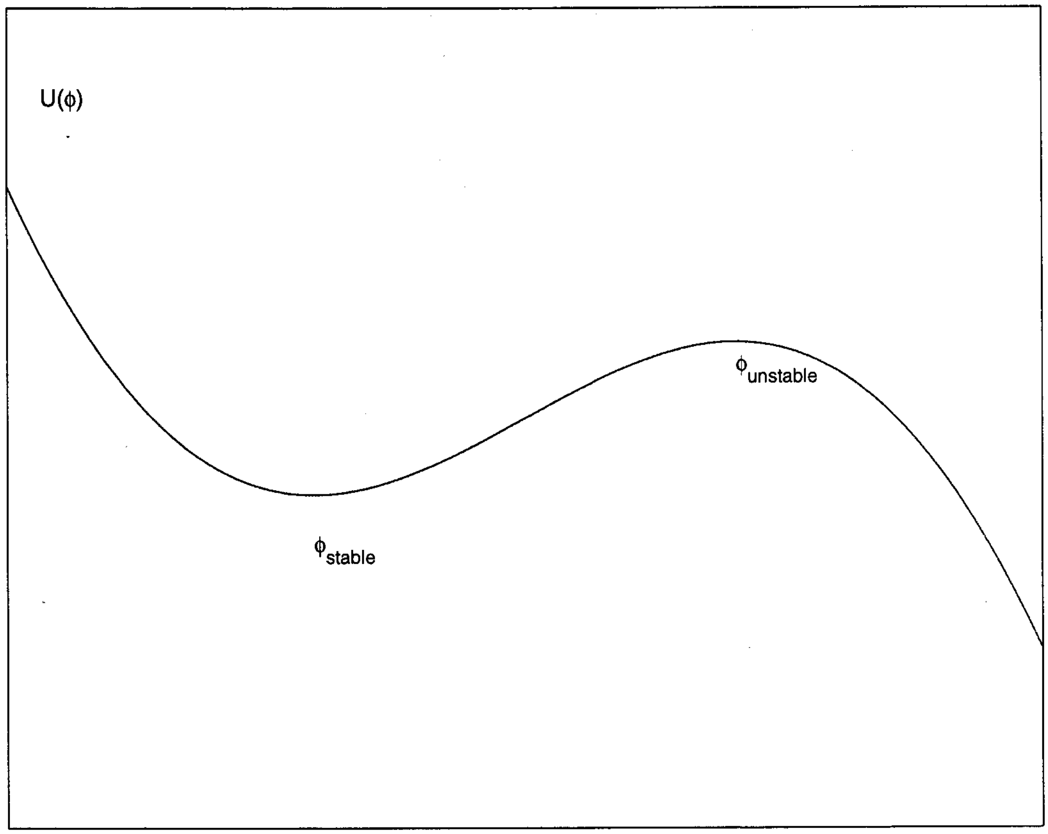
20. This work was supported by the Jet Propulsion Laboratory of the California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

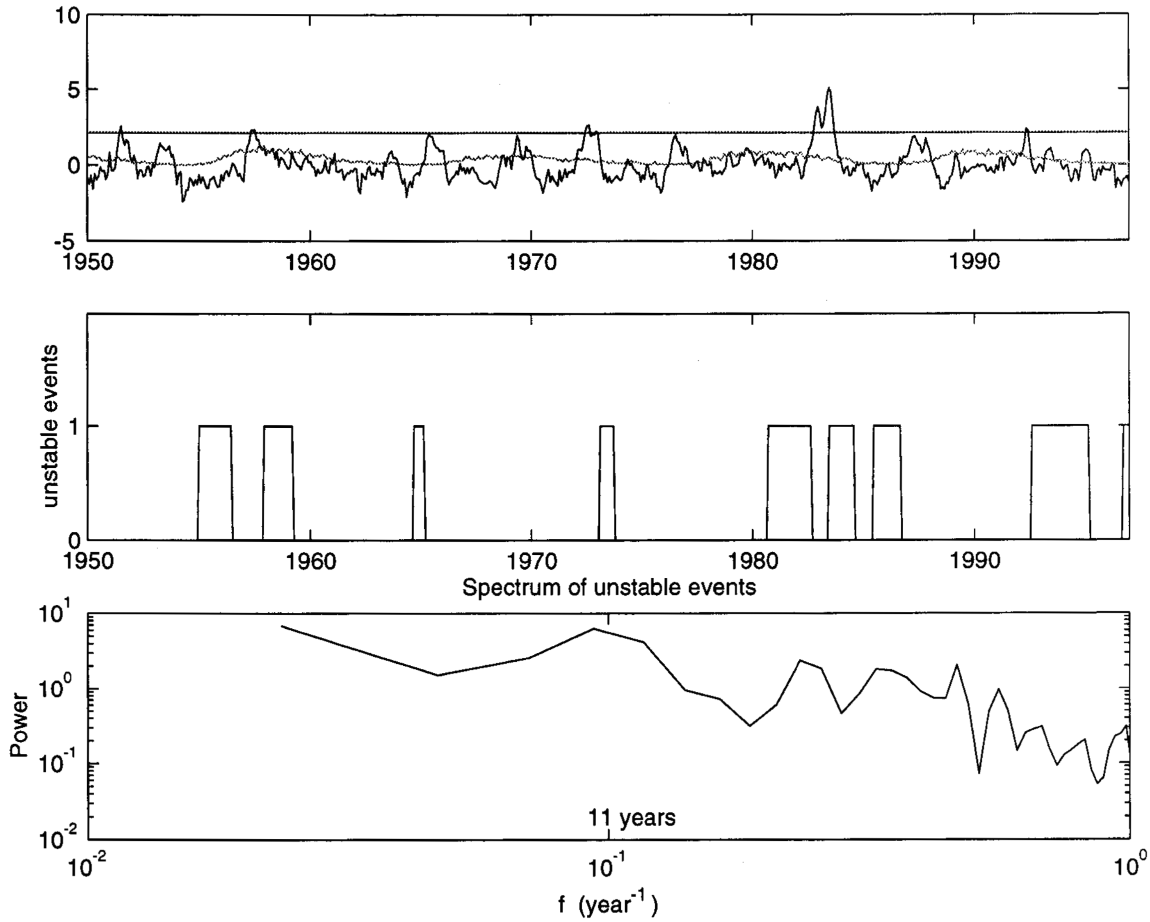
Figure captions

Fig. 1. The model presentation of stable and unstable states of the atmosphere.

Fig. 2. Upper panel: Time series of ENSO (solid line) and solar activity (dotted line), the straight line marks the threshold; Middle panel: The events corresponding to the situation when the sum of ENSO and solar forcing crossed the threshold between the stable and unstable states; Low panel: Spectrum of the events. Because the time series is short, the function in the middle panel was periodically expanded to show the spectrum more clearly.



U(ϕ)
ϕunstable
ϕstable


10
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0
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Spectrum of unstable events
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10^{1}
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